PREDICTIONS OF CLIMATE CHANGE IMPACTS ON CALIFORNIA WATER RESOURCES USING CALSIM-II: A TECHNICAL NOTE

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WHITE PAPER

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DISCLAIMER

Arnold Schwarzenegger, *Governor*

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Acknowledgements

Preface

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The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

Table of Contents

Preface ii
1.0 Introduction 1
2.0 Methods 1
3.0 Results 2
3.1. Impact on Hydrology 2
3.2. Water Resources System Impacts 3
4.0 Conclusions 4
5.0 References 4

List of Figures

Figure 1. Perturbation change ratio in monthly streamflow in selected rivers in the Sacramento and San Joaquin Basins under GFDL, PCM and HadCM3climate change scenarios 8

Figure 2. Changes in drought conditions for all climate scenarios 9

Figure 3. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A2 and GFDLB1-A2 for 2070-2099 10

Figure 4. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 11

Figure 5. Exceedance probability plot of CVP South of Delta Annual Deliveries under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 12

Figure 6. Exceedance probability plot of CVP South of Delta Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 13

Figure 7. Exceedance probability plot of SWP Annual Deliveries under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 14

Figure 8. Exceedance probability plot of SWP Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 15

Figure 9. Exceedance probability plot of CVP end of September Carryover Storage under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 (includes storage in Shasta, Trinity, Folsom and CVP San Luis) 16

Figure 10. Exceedance probability plot of CVP end of September Carryover Storage under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 (includes storage in Shasta, Trinity, Folsom and CVP San Luis) 17

Figure 11. Exceedance probability plot of SWP end of September Carryover Storage under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 2070-2099 (includes storage in Oroville and SWP San Luis) 18

Figure 12. Exceedance probability plot of SWP end of September Carryover Storage under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099 2070-2099 (includes storage in Oroville and SWP San Luis) 19

List of Tables

Table 1. Relative proportion of years classified as wet, above normal, below normal, dry and critical based on the Sacramento 40-30-30 Index for the historic and climate change predicted conditions. 7

1.0 Introduction

The following technical note describes the methodology used to assess the impacts of different climate change scenarios on California water resources. To analyze the performance of California's water system under predicted hydrologic scenarios associated with climate change requires the aid of a water resources systems model. In this project we used CalSim-II a model cooperatively developed by the California Department of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR). CalSim-II was used previously by Brekke et al. (2004) and Vicuña et al (submitted) to estimate the impacts of climate change on California water resources.

For this project, CalSim-II was applied to hydrologic conditions developed by the Variable Infiltration Capacity (VIC) method from 7 different climate change scenarios. Four of these scenarios include the outputs from the Parallel Climate Model (PCM) and the Geophysical Fluid Dynamic Laboratory (GFDL) General Circulation Models (GCM) run using the A2 and B1 SRES emission's scenarios. The three other scenarios are those considered in the study by Hayhoe et al. (2004) and Vicuña et al. (submitted) which involved a new emission scenario (A1fi) for the PCM model and two more scenarios (A1fi and B1) generated by the U.K. Hadley Centre Climate Model, version 3 (HadCM3).

The following section describes the methodological aspects of this project. The results follow, together with a brief conclusion.

2.0 Methods

The methods used to assess climate change impacts on water resources systems have been reviewed previously by Gleick (1989), Wood et al. (1997) and Dracup and Vicuña (2005). There are generally two stages of analysis. The first determines changes in unimpaired stream flow at inflow points to the managed water system, and the second uses these changes to drive a water resources systems model. In this study we focus only on the second stage. Data needed from the first stage was derived using the VIC model as explained in Cayan et al. (In review) and Vicuña et al. (submitted).

To simulate the impacts of potential changes in hydroclimatology on water resource systems we employed the simulation model CalSim II. CalSim II is a network-flow programming model developed jointly by the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR) to represent the joint Central Valley Project (CVP)–State Water Project (SWP) water supply delivery system. Extensive descriptions of CalSim II can be found on Munevar and Chung (1999), Brekke et al (2004), Draper et al (2004) and Quinn et al. (2004). Model output includes monthly reservoir releases, river flows, reservoir stored water volumes, water deliveries, Delta export activities, and indicators of Delta water quality conditions. In this study we have focus our attention on water deliveries and reservoir storage for the two main supply projects, the CVP and SWP.

A baseline version of the model called CalSim II Benchmark Studies (DWR/USBR, 2002) was built to produce monthly operations decisions for a 73-year simulation period (1922 through 1994) as experienced in the Central Valley. Water demands and system infrastructure were modified to represent a year 2020 level of development. For this work we applied the model under implementation of the Delta Water Quality Control Plan as codified in California State Water Rights Decision 1641 (D1641). The ANN model was used to estimate water salinity at various locations in the Delta as function of net Delta outflow (DWR/USBR, 2002).

To run CalSim-II using the perturbed hydrologic conditions of the seven different climate change scenarios, we modified the historical 73 years of reservoir inflows by multiplying every monthly datum by a perturbation ratio. These perturbations ratios were obtained by dividing monthly average runoff as simulated by VIC for the period 2070-2099, by the monthly average values for 1961-1990.[1] All other inputs to the model, such as local water supplies, water consumption among urban and agricultural users, water allocation contracts, and reservoir operations regulations were preserved following Brekke et al. (2004). The only input we modified was the set of risk tolerance curves, the Water Supply Index–Demand Index curves (WSI-DI), that determine the annual delivery allocations for both the SWP and CVP according to water supply levels (Draper et al., 2004). Since water supplies were projected to be significantly altered with climate change, new WSI-DI curves were generated for each climate change scenario using an automated procedure included in CalSim II.

3.0 Results

3.1. Impact on Hydrology

Figure 1 shows the hydrologic impacts of the climate change scenarios in terms of *perturbation ratios*. A perturbation ratio is the ratio of the value of the relevant variable (e.g., average monthly streamflow on the Sacramento River over the period 2070-2099) under a certain scenario (e.g. PCM A2) to the corresponding value of the same variable in the same month under baseline (historical) conditions. Figure 1 shows the monthly perturbation ratios for selected major rivers in the Sacramento and San Joaquin basins under the 7 climate change scenarios for period 2070-2099.

The results show lower summer and late-spring runoff for all river basins. Results for other seasons are less consistent reflecting differences in winter precipitation predictions among the different GCMs. For example, those scenarios that show increased in winter precipitation also show the highest runoff perturbation ratios in winter months (e.g. PCM B1). The graphs show similar annual flow patterns for each GCM but different impact amplitudes depending on the GHG emission scenario. The output of PCM shows a relative increase in streamflows during mid-late winter as compared to the rest of the year, with the highest relative impacts during the spring. In contrast, the GFDL and HadCM3 results show relative decreases in streamflows in nearly all months except late fall and early winter.

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[1] Due to an infeasible solution (while trying to simulate the 1976-77 drought) CalSim-II could not complete the simulation of the GFDL A2 climate scenario. As a fix to overcome this problem, we used inflow conditions corresponding to the GFDL B1 climate change scenario for the 1976-77 water years; this produces a somewhat optimistic projection of the potential impacts under the GFDL A2 climate change scenario.

As part of the analysis of changes in hydrologic conditions associated with the climate change scenarios we estimated the change in the relative proportion of years classified under different water year types (see Table 1). The methodology considered the Sacramento Four River Index (also called Sacramento 40-30-30 Index) to determine the water year type. This index classifies water years in 5 categories: Wet, Above Normal, Below Normal, Dry and Critical.[2] Because the River Index pays greater attention to the aggregate stream flow than the timing of flow, it is more influenced by changes in precipitation than temperature. The projections for the less dry model (PCM) suggest that toward the end of the century, under the higher-emissions scenario, up to 50% of the years between 2070-2099 could be critically dry years as compared to 18% in the historical period. Under the lower-emissions scenario in the less-dry model little or no change in the frequency of critically dry years is expected. In contrast, in the drier models (HadCM3 and GFDL), the projections suggest that even under the lower-emissions scenarios the frequency of critically dry years could be up to twice as often as historical conditions.

An additional analysis estimates possible future changes in hydrologic conditions in terms of drought persistence. To represent drought conditions we are using only the 40-30-30 Sacramento Four River Index; a drought is considered to occur in a given year if the index for that year falls below the dry threshold. We calculate for each year an accumulated deficit representing the positive difference between the "dry" threshold and the 40-30-30 Index. Deficits are accumulated in consecutive dry years, but whenever the index is above the "dry" threshold, the deficit is reset to 0. Figure 2 show the accumulated deficits for the historic period and for the 7 climate change conditions we have included in this analysis. The results show that drought conditions will be better than under the historic case for the PCM B1 and A2 scenarios but worse for all the other scenarios under which both the magnitude and duration of droughts might be exacerbated.

3.2. Water Resources System Impacts

There are several variables that could be used as performance indicators to assess the climate change impacts on California water resources systems These include reservoir storage levels, water supply deliveries, and variables measuring environmental conditions in the Delta and elsewhere. Here we use the first two indicators, reservoir storage and deliveries south of the Delta, and consider only the two major government

[2] The Sacramento River Index was developed by the State Water Resources Control Board for regulatory purposes, and requires the forecasting by May of each year of the current year's April–July unimpaired runoff in the Sacramento Valley. When a retrospective analysis is conducted using the historical hydrology, as here, the actual April–July runoff is known, but not the prospective forecast, and therefore the index cannot be calculated in exactly the same way. The research here uses the Brekke et al. (2004) retrospective approximation for calculating the index.

water supply projects, the CVP and SWP (results for other users or other variables are available from the author on request). Figures 3 through 12 show the exceedance probabilities of carryover reservoir storage, and north of delta and south of Delta CVP and SWP deliveries under all 7 different climate change scenarios. The exceedance probability curves indicate the probability that a given water supply delivery level will be achieved or exceeded.

It is clear (and expected) that the results in terms of water resources impacts follow the same pattern already discussed for the impacts on hydrology. There is only one scenario (PCM B1) that shows relative small impacts for the California water resource systems. All other scenarios show dramatically negative impacts to reservoir storage and water supply deliveries. Clearly, the impacts are higher for scenarios under higher GHG emissions for the three GCMs.

Comparing the impacts on water delivery for north of the Delta to south of the Delta we see that the impacts tend to be greater south of the Delta. This difference is due in part to the effect of environmental regulations, which limit exports to the South of the Delta and weaken the reliability of water deliveries to South water rights holders.

4.0 Conclusions

We have presented in this technical note the methodology we have used to assess the impacts of different climate change scenarios on California water resources. The methodology involved modifying the historic time series of inflows that is used to drive the DWR/USBR's CalSim-II water resources model. We have considered in this analysis 7 different climate scenarios as predicted by 3 GCMs (GFDL, PCM and HadCM3) run under different GHG emission scenarios.

Results show great negative impacts on California hydrology and water resources associated with most of climate change scenarios analyzed (only one scenario PCM run under B1 emission scenarios show just mild negative impacts).

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Tables

Table 1. Relative proportion of years classified as wet, above normal, below normal, dry and critical based on the Sacramento 40-30-30 Index for the historic and climate change predicted conditions.

	Wet	Above Normal	Below Normal	Dry	Critical
Hist	34%	14%	12%	22%	18%
PCMB1	40%	11%	19%	14%	16%
PCMA2	33%	11%	16%	18%	22%
PCMA1fi	8%	8%	16%	11%	56%
GFDLB1	26%	12%	12%	14%	36%
GFDLA2	7%	15%	8%	19%	51%
HadB1	18%	10%	16%	7%	49%
HadA1fi	14%	12%	12%	12%	49%

Average of 73 years (1922-1994)

Figures

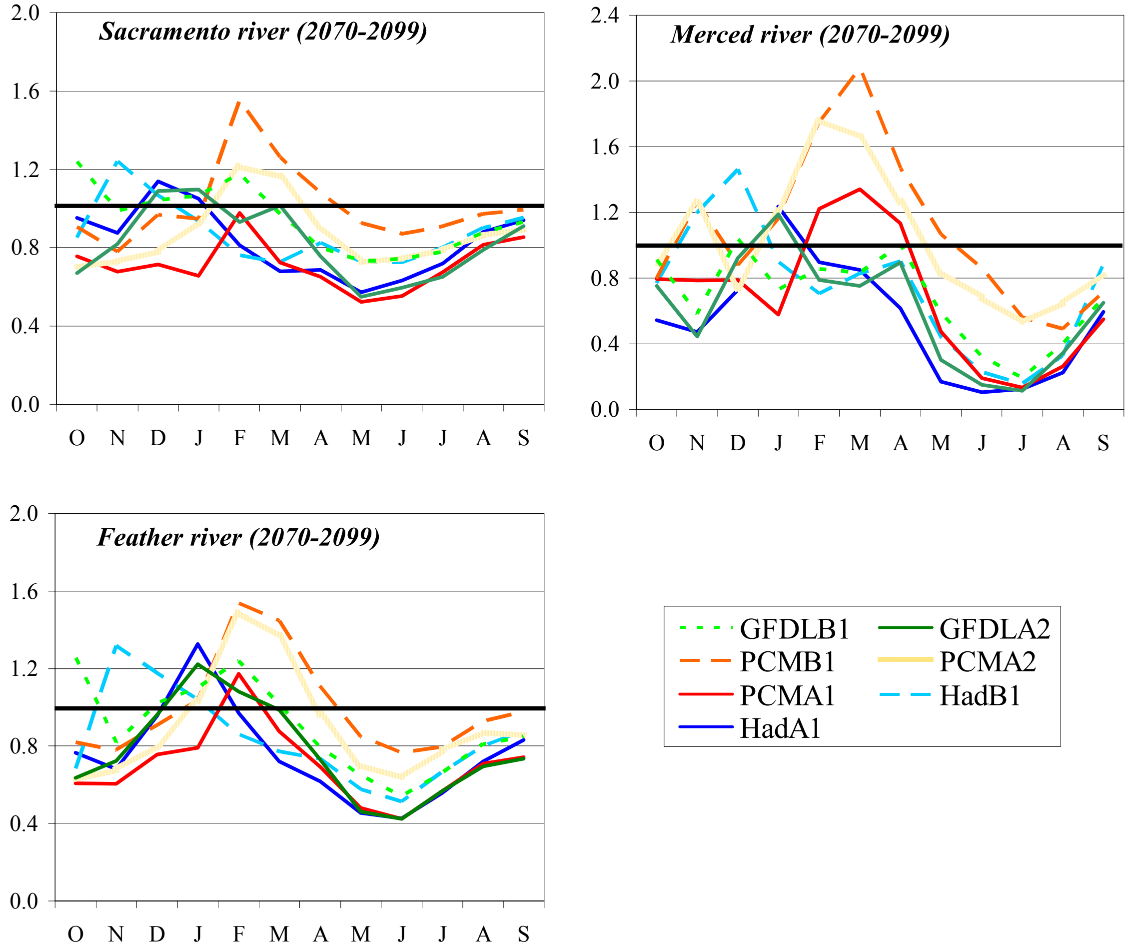


Figure 1. Perturbation change ratio in monthly streamflow in selected rivers in the Sacramento and San Joaquin Basins under GFDL, PCM and HadCM3climate change scenarios

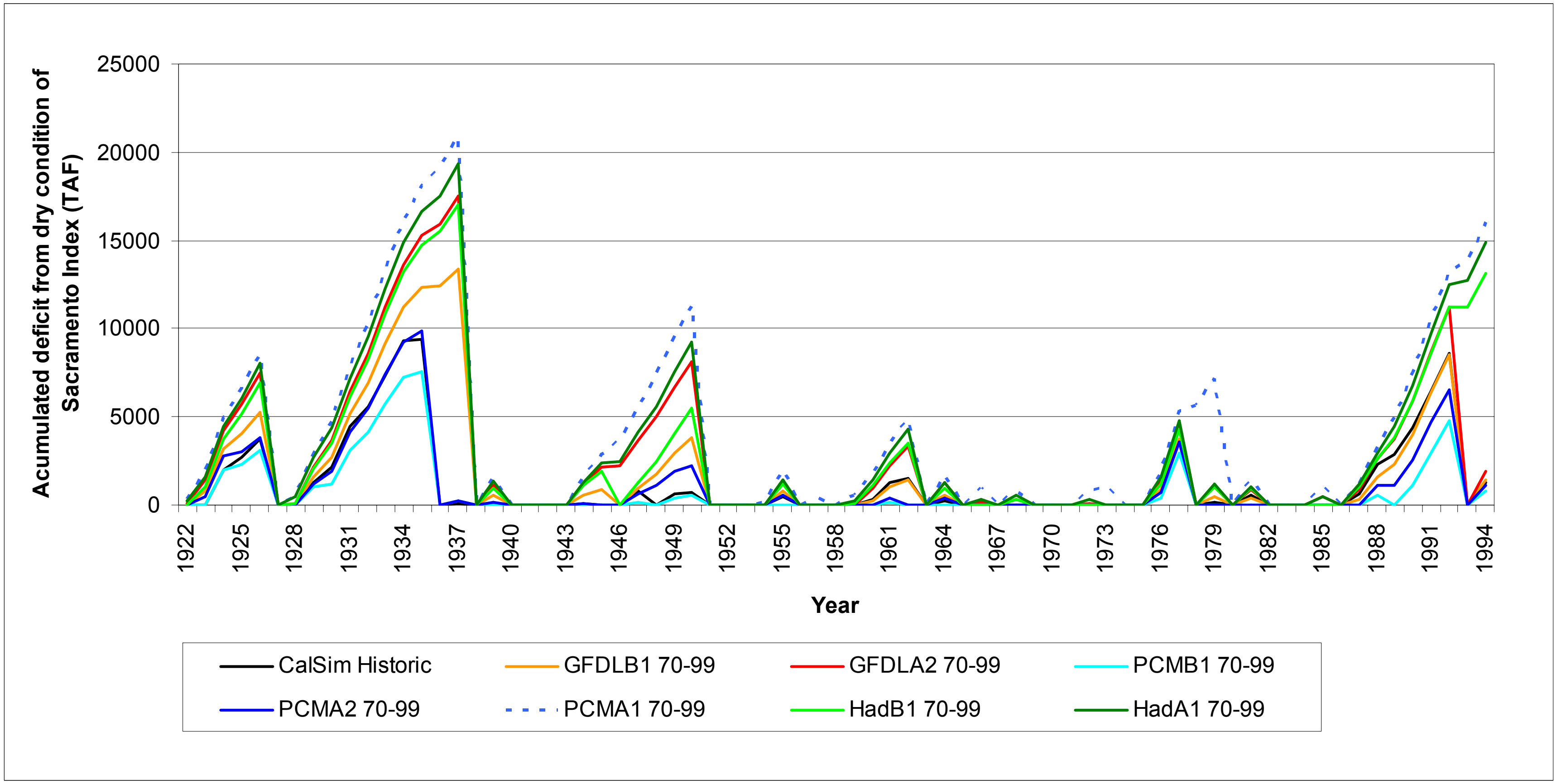


Figure 2. Changes in drought conditions for all climate scenarios

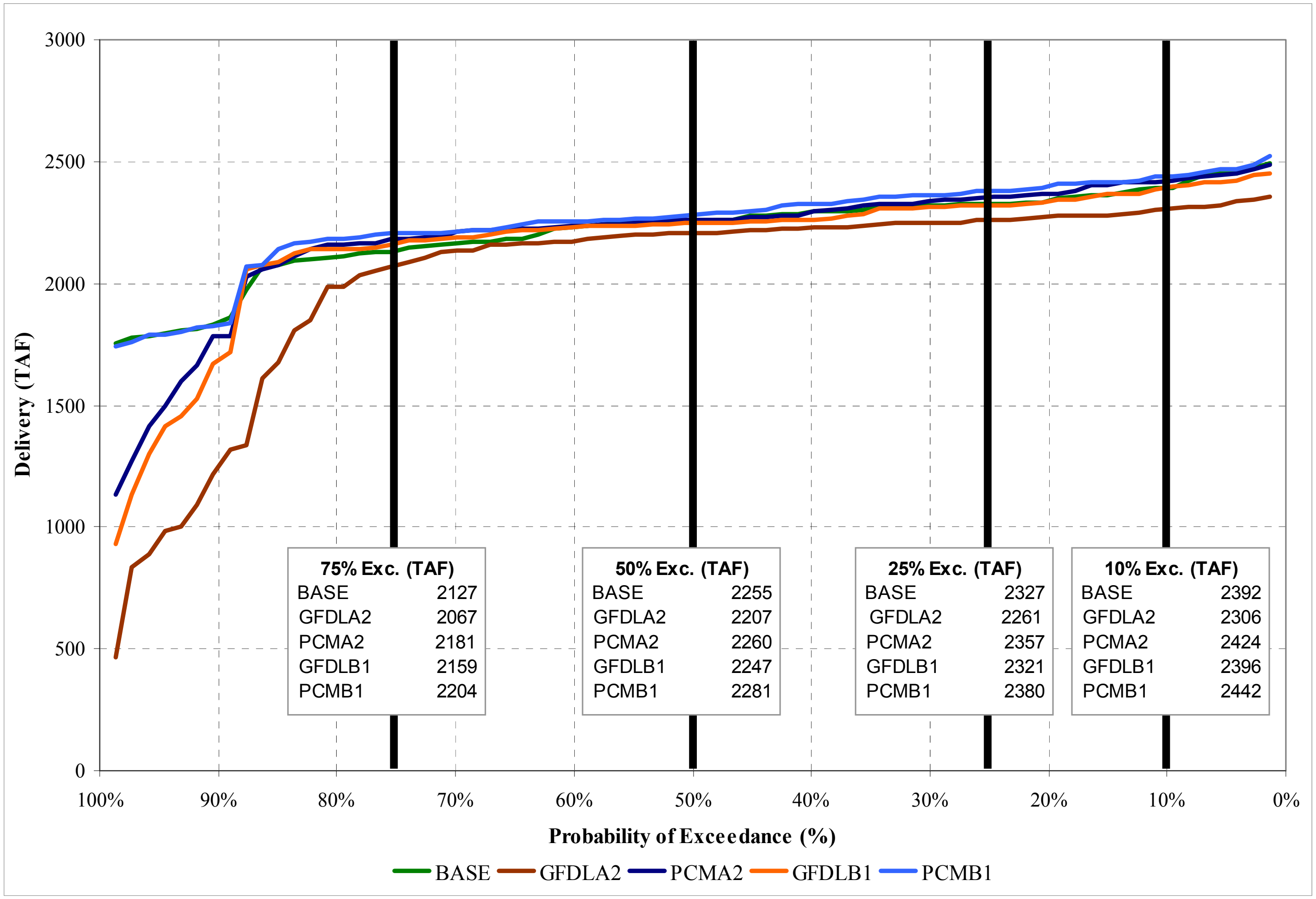


Figure 3. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A2 and GFDLB1-A2 for 2070-2099

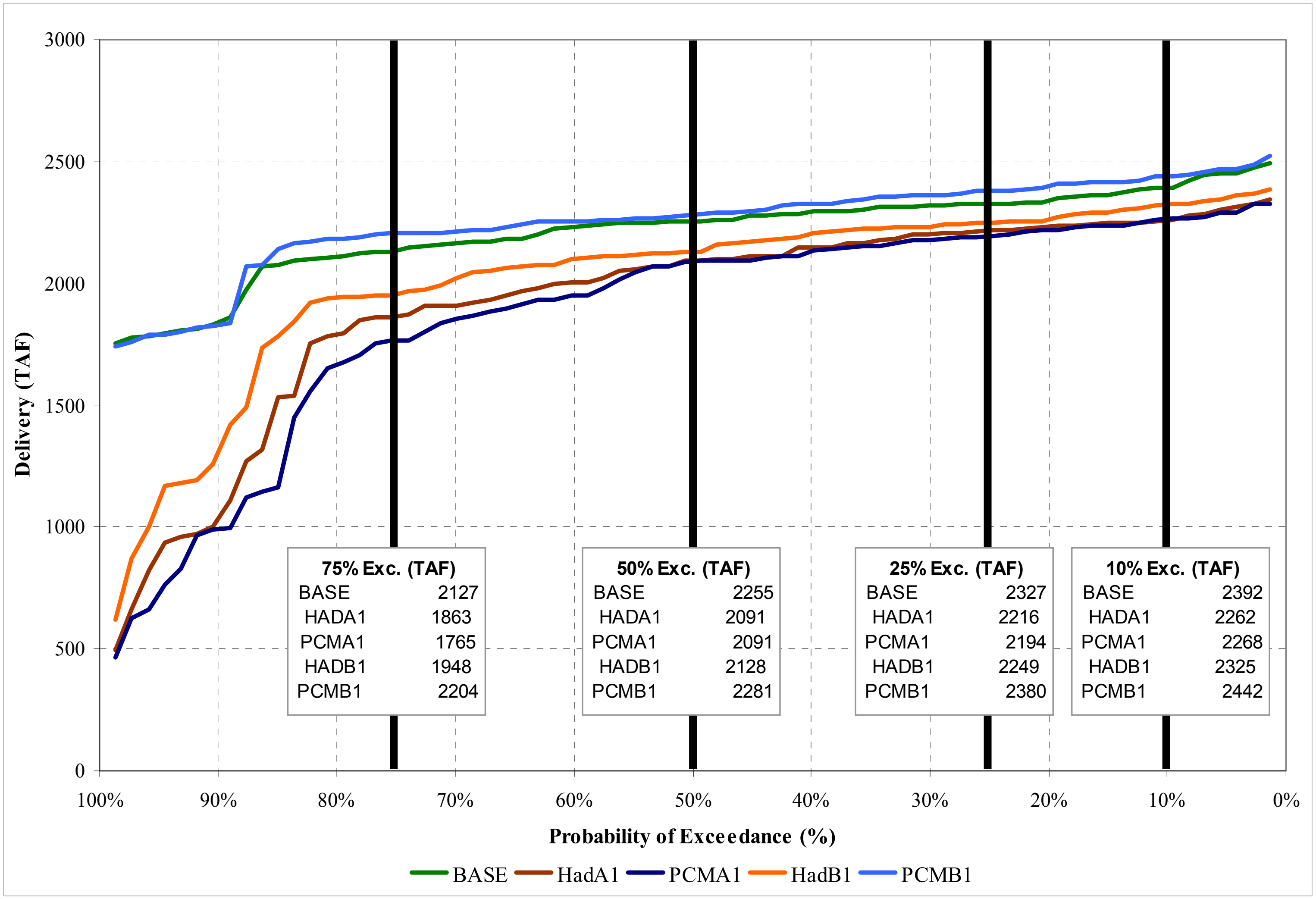
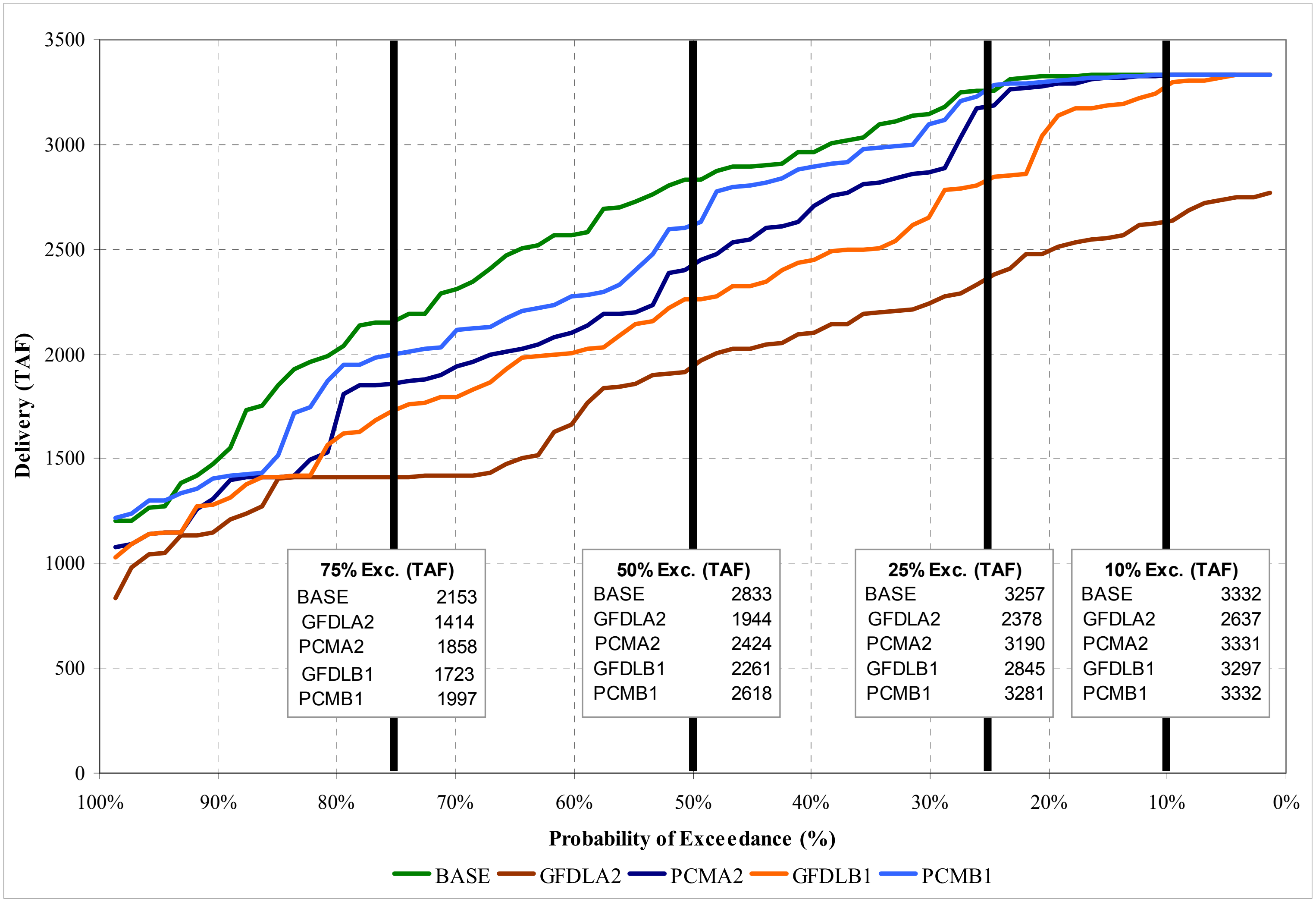


Figure 4. Exceedance probability plot of CVP North of Delta Annual Deliveries under climate change scenarios PCM B1-A1 and HadCM3 B1-A1 for 2070-2099



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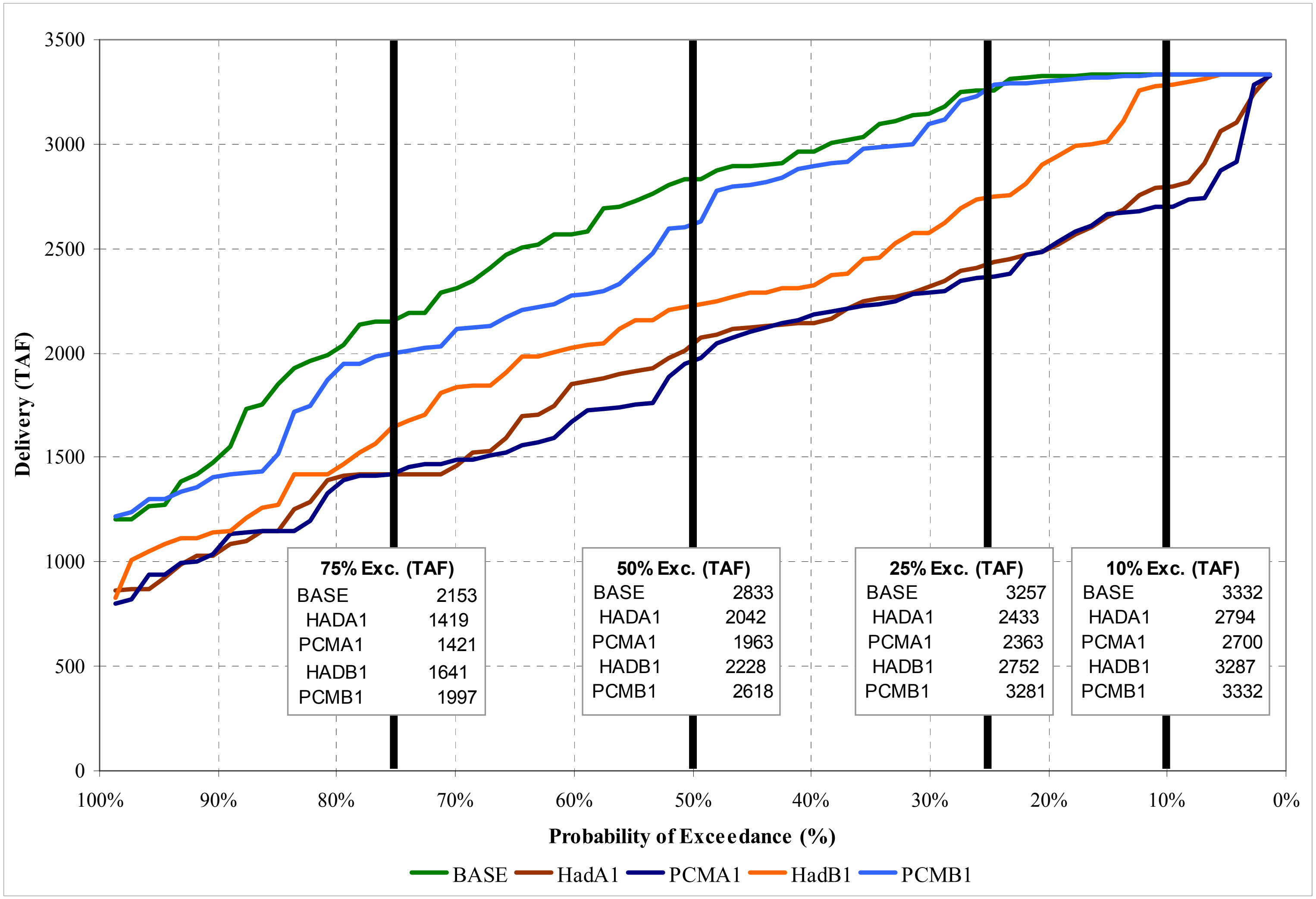

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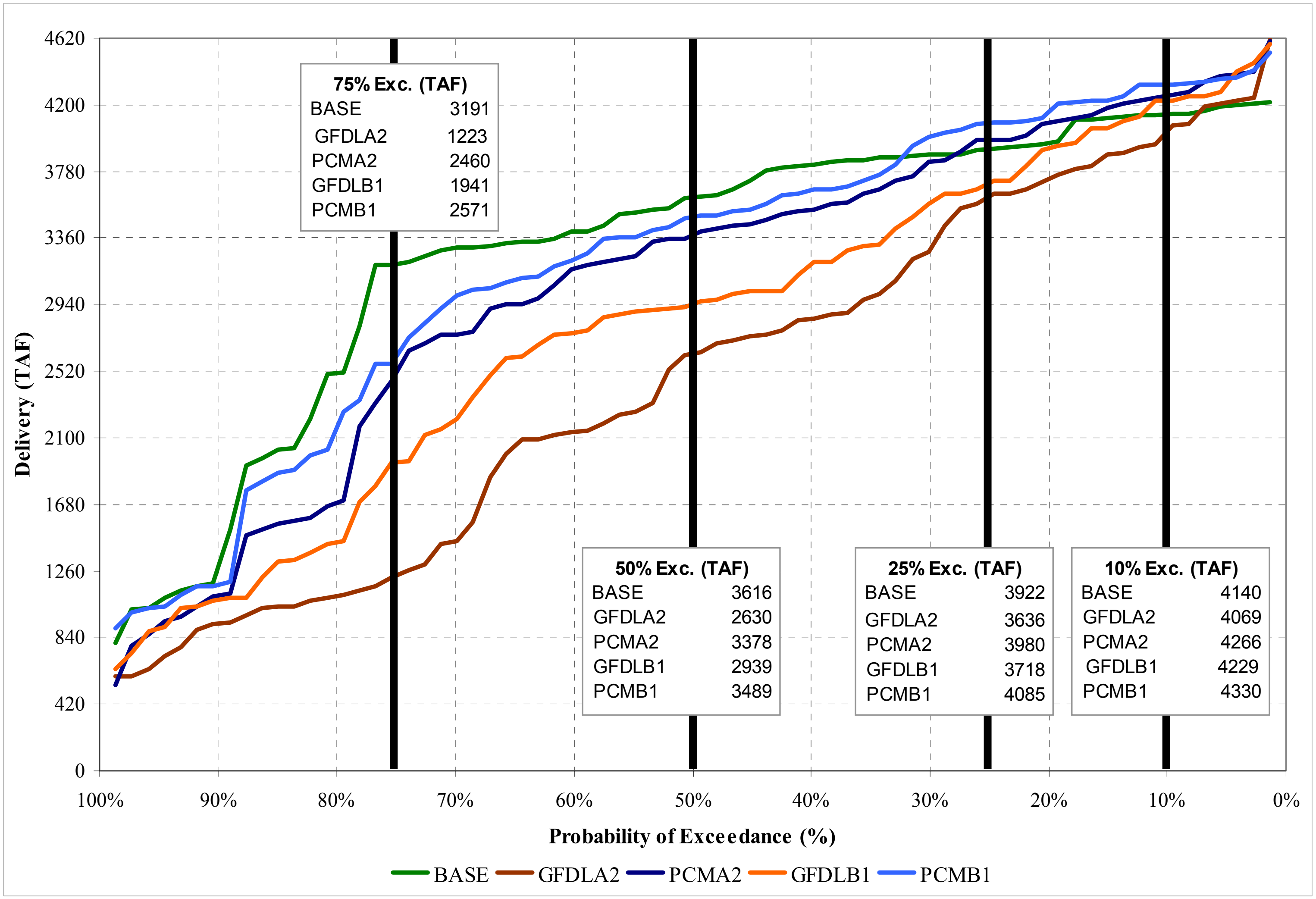

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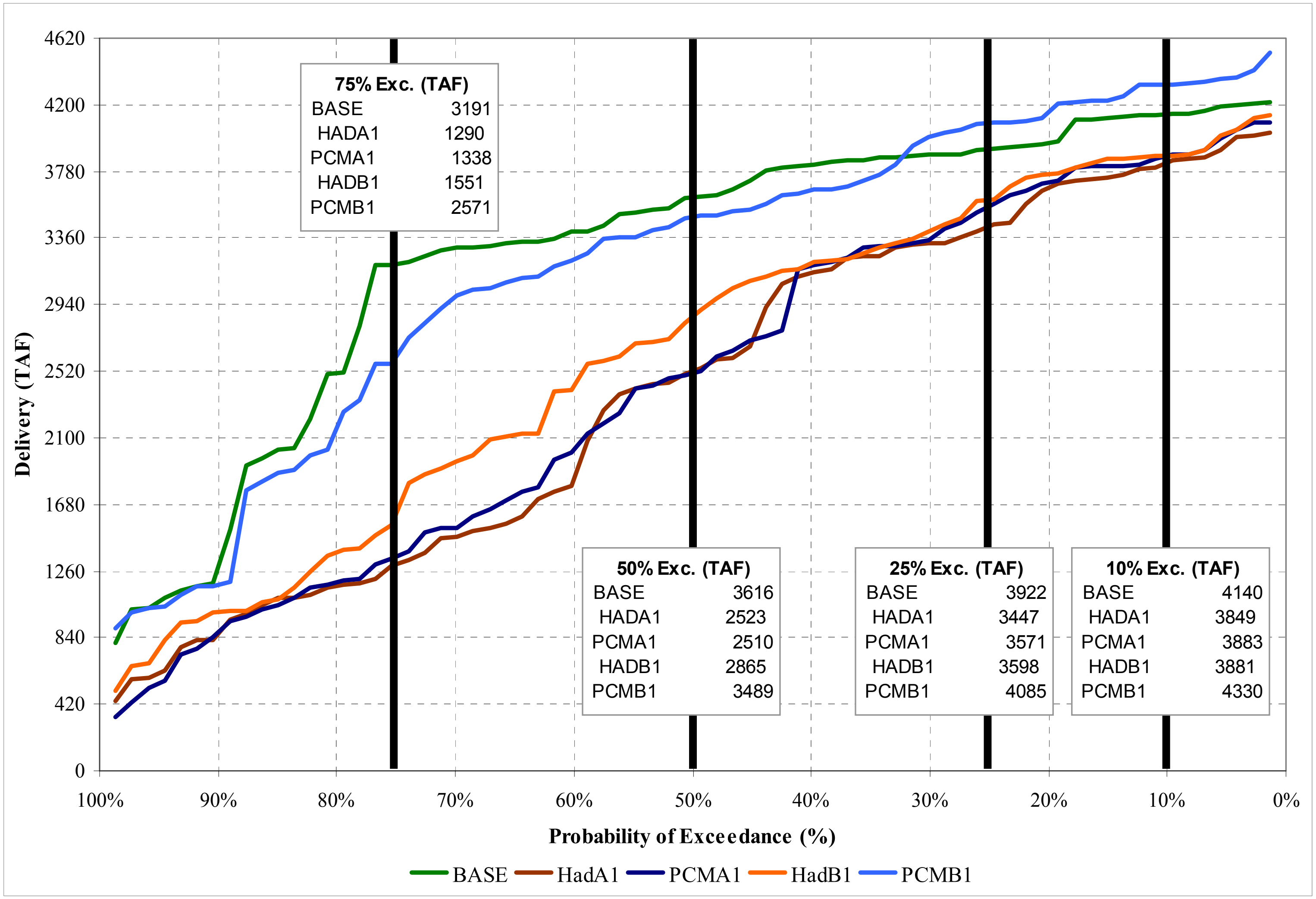

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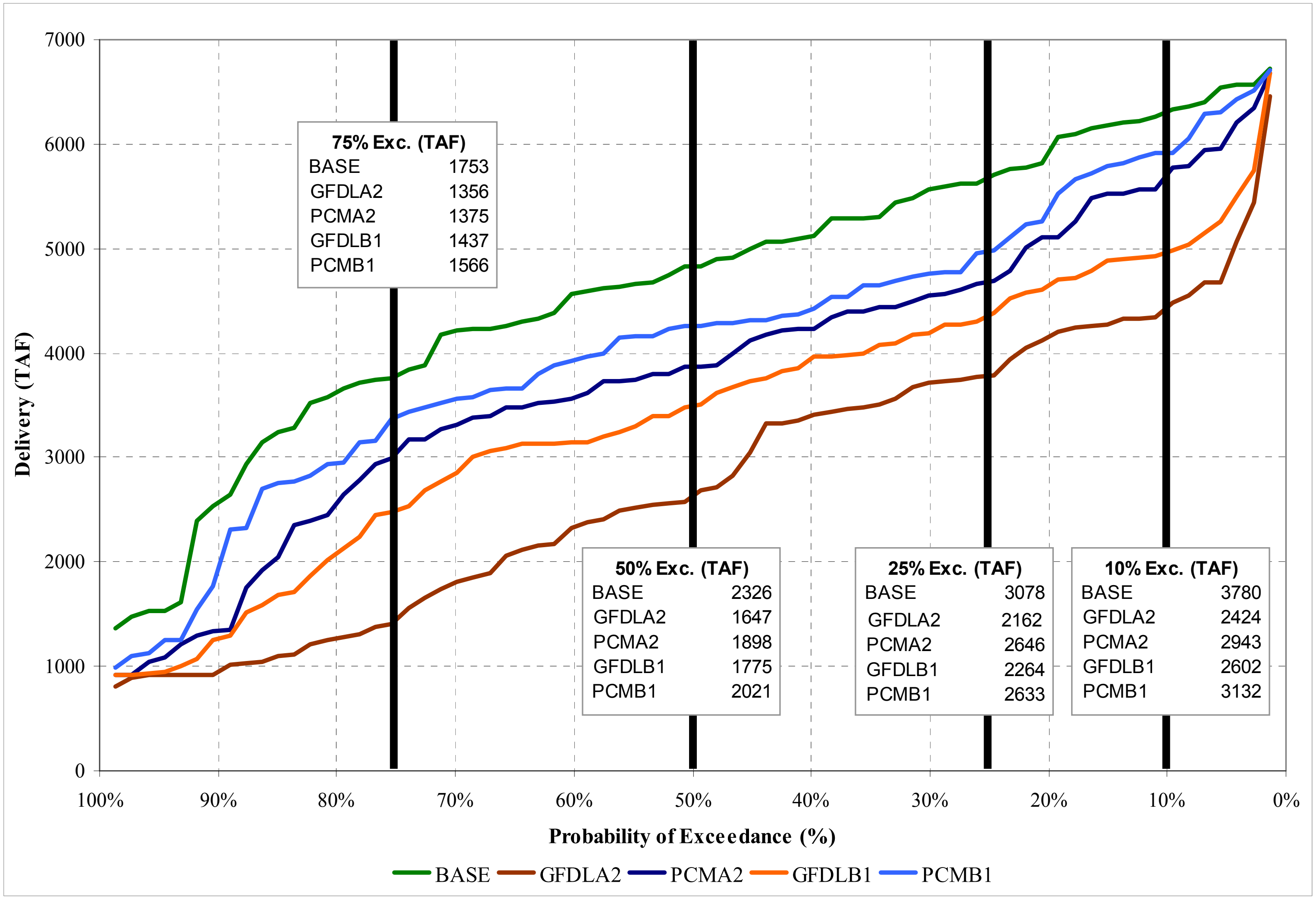
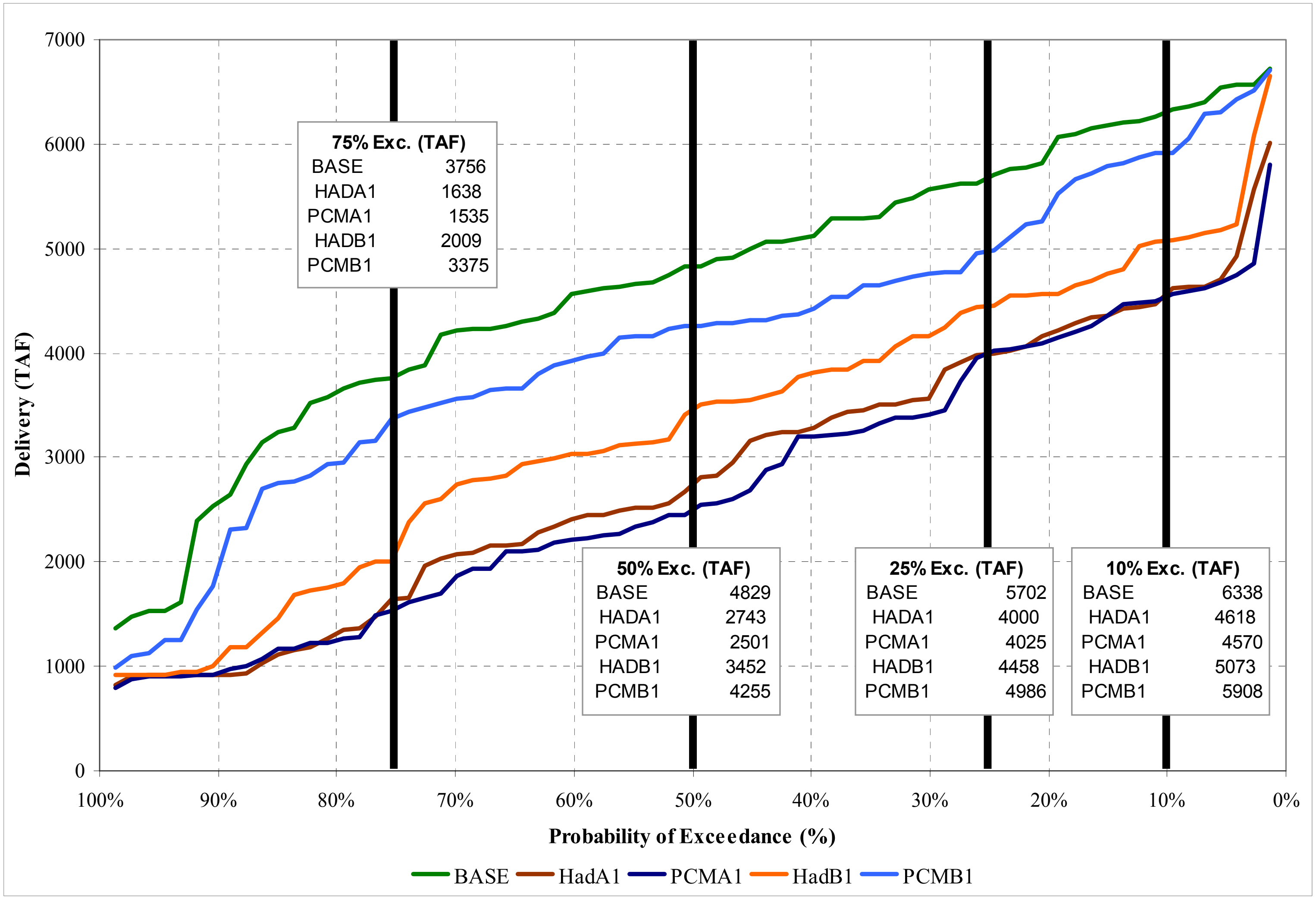


Figure 9. Exceedance probability plot of CVP end of September Carryover Storage under climate change scenarios PCM B1-A2 and GFDL B1-A2 for 2070-2099 (includes storage in Shasta, Trinity, Folsom and CVP San Luis)



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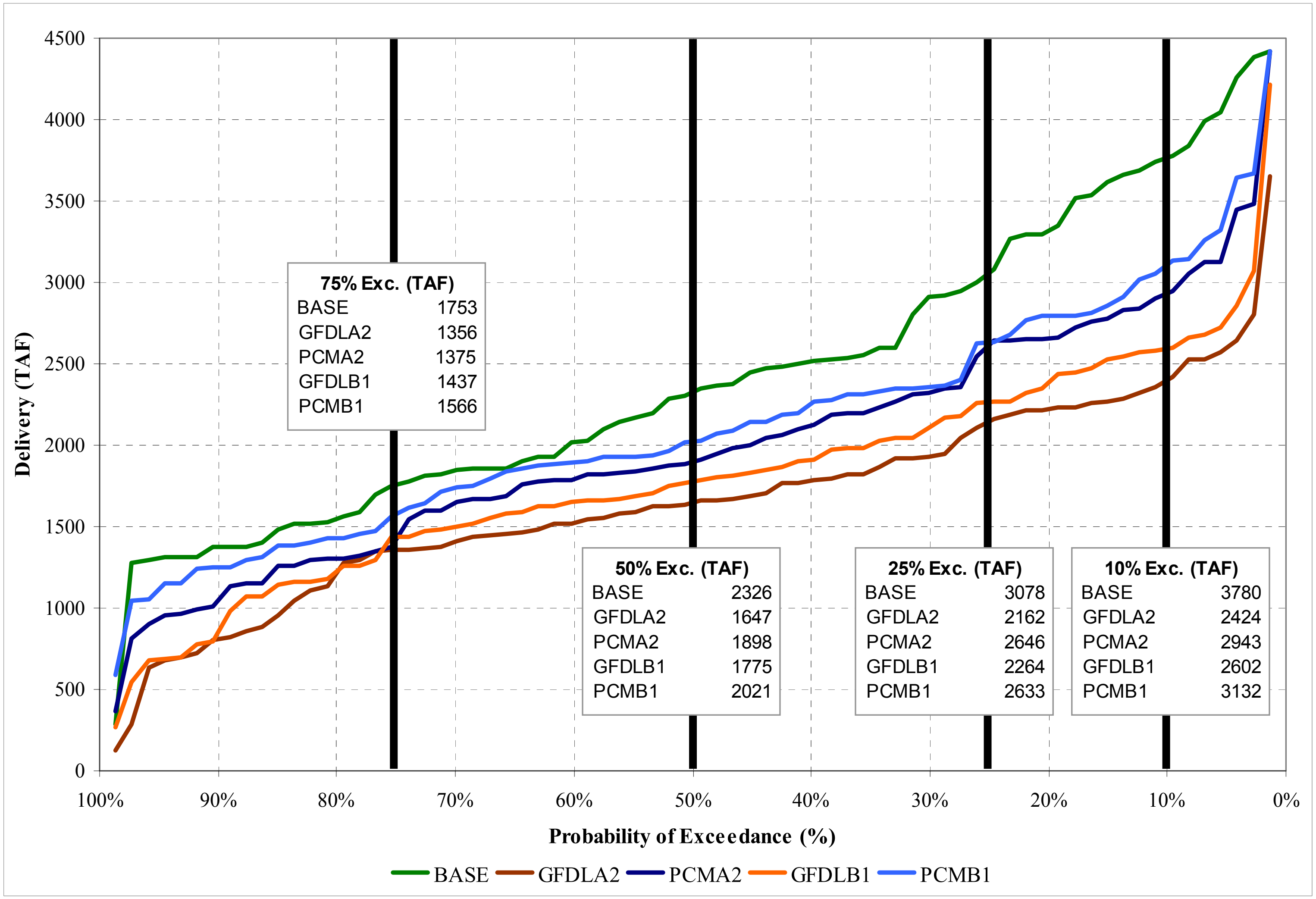

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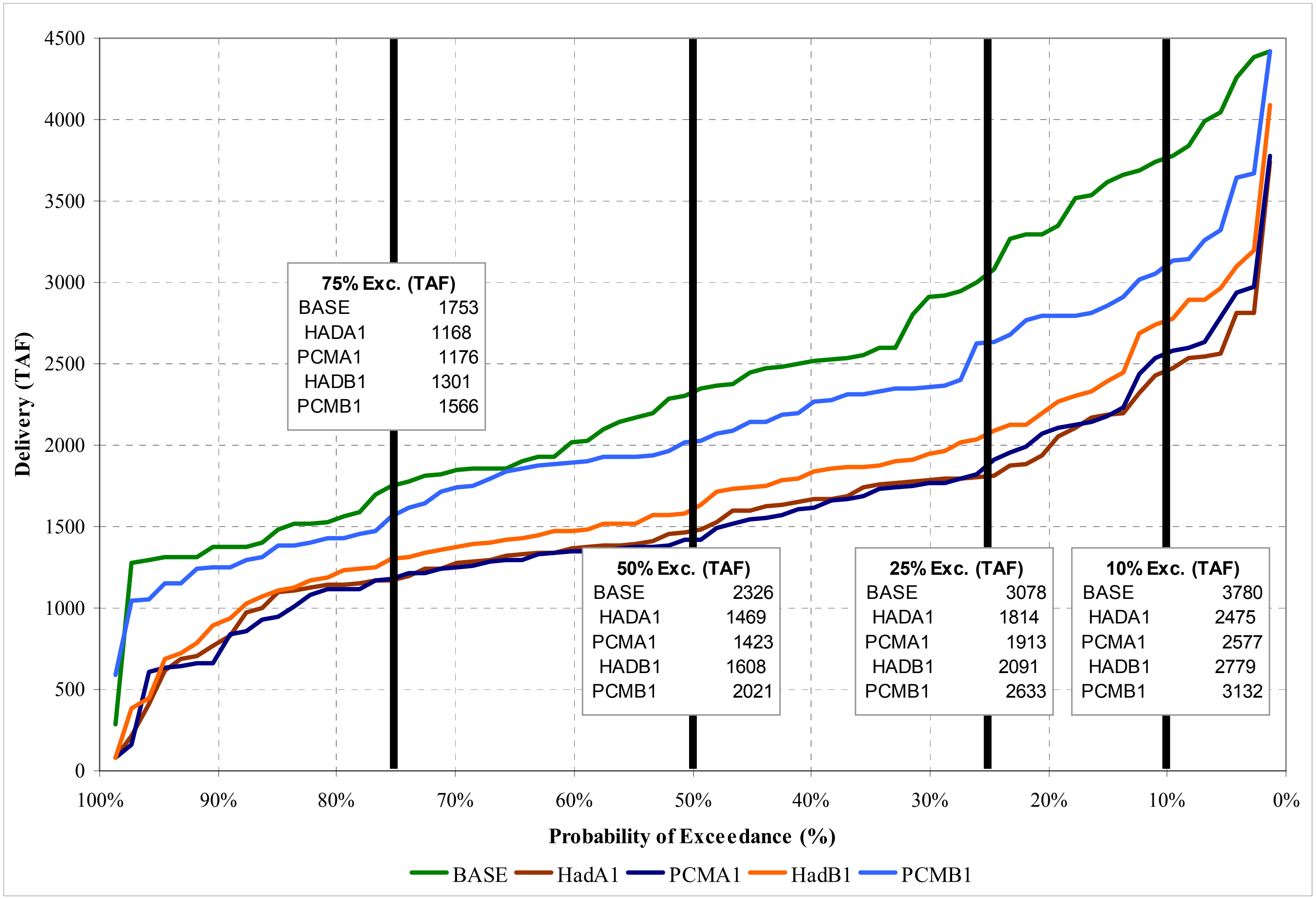

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